

Status of Ignition Experiments on the NIF



NIF/JLF Users Group Meeting
Livermore, CA

February 11th, 2015

**Lawrence Livermore
National Laboratory**

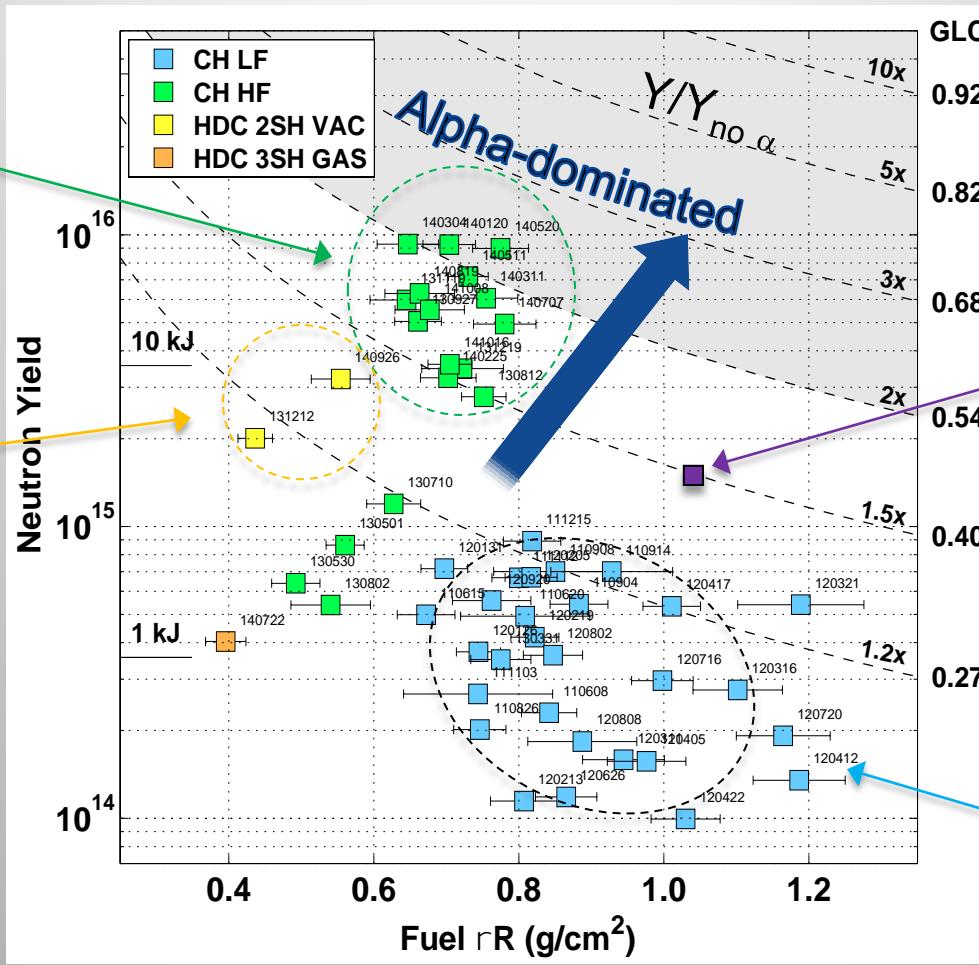
LLNL-PRES-667243

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC

We are developing a promising path forward with low mix, high velocity implosions and improving symmetry control to reach toward higher yields

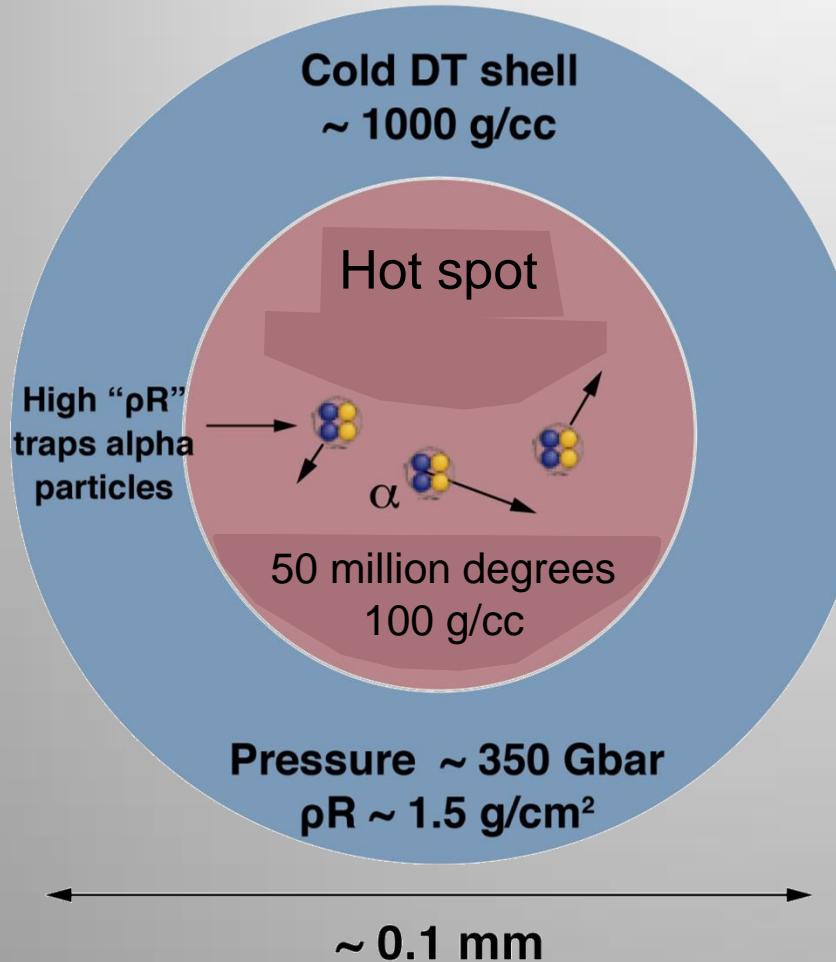
High foot

HDC NVH



Ignition requires compression to high pressures and temperatures in short time scales to self-heat

Heating from fusion > Cooling from conduction & x-ray losses



$$E_{ignition} \sim \frac{[(\rho R)^3 T^3]_{DT}}{P_{stag}^2} \rightarrow \frac{const.}{P_{stag}^2}$$

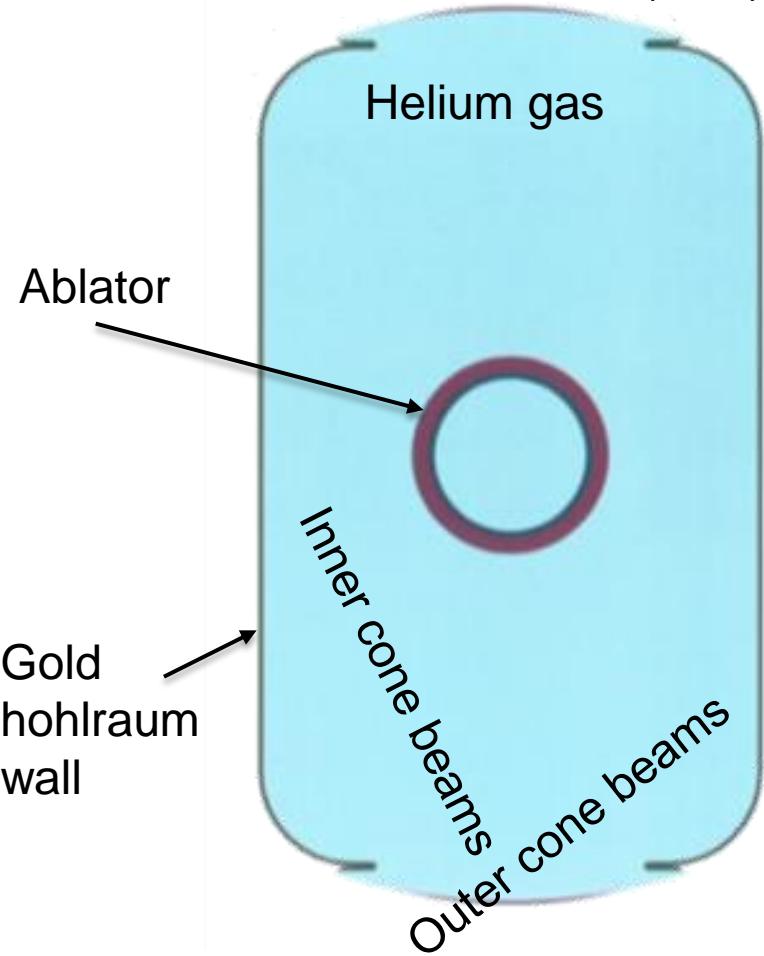
Stagnation pressure depends on how the hot spot was assembled:

$$P_{stag} \sim P_{abl}^{2/5} \frac{v_{imp}^3}{\alpha^{9/10}} \epsilon$$

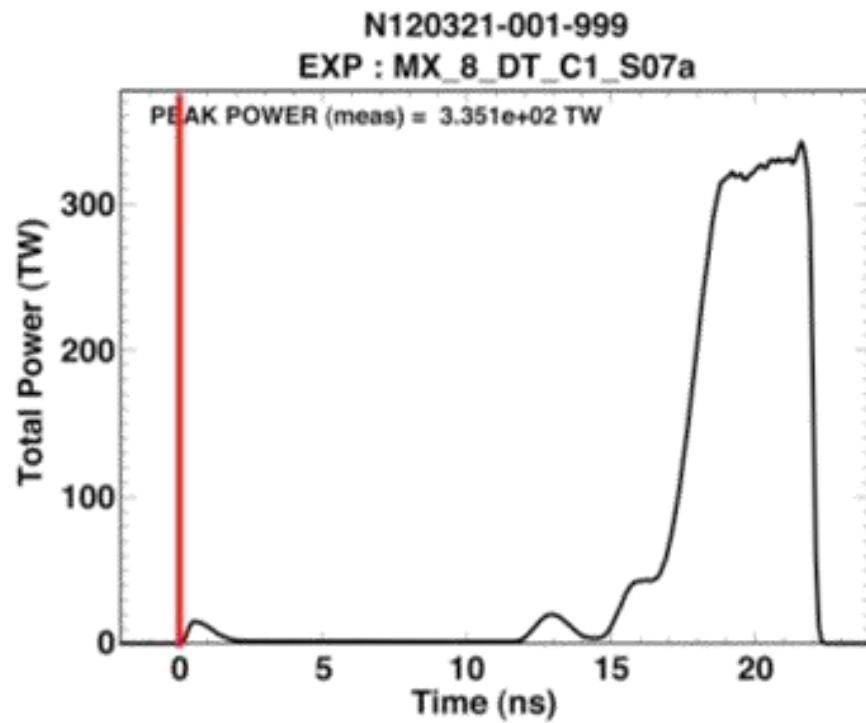
* ρR = Areal density

On the NIF, we use a laser driven hohlraum to implode the capsule attempting to create conditions needed for ignition

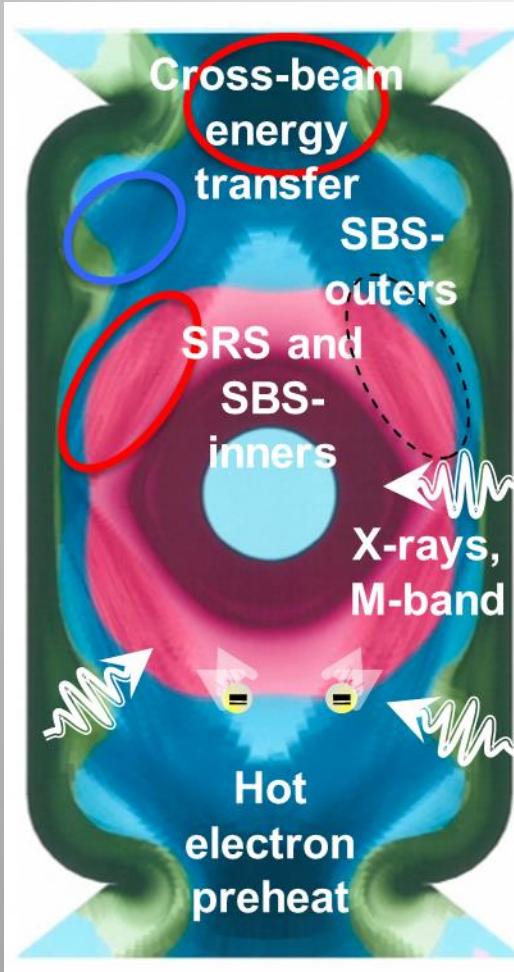
Laser entrance hole (LEH)



Laser "Pulse-shape"

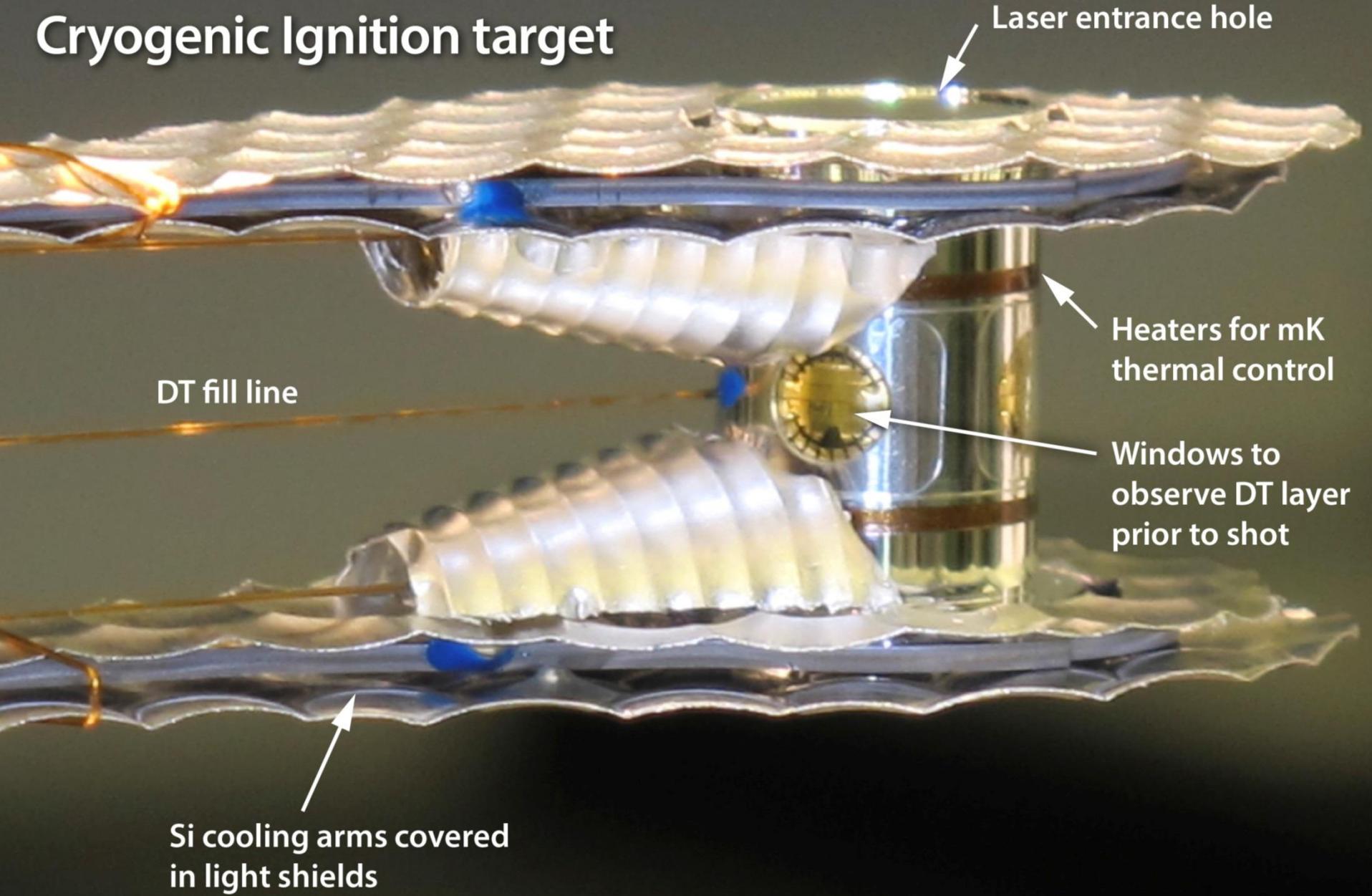


Hohlraum dynamics are complicated, and diagnosing plasma conditions is an area of active, ongoing research

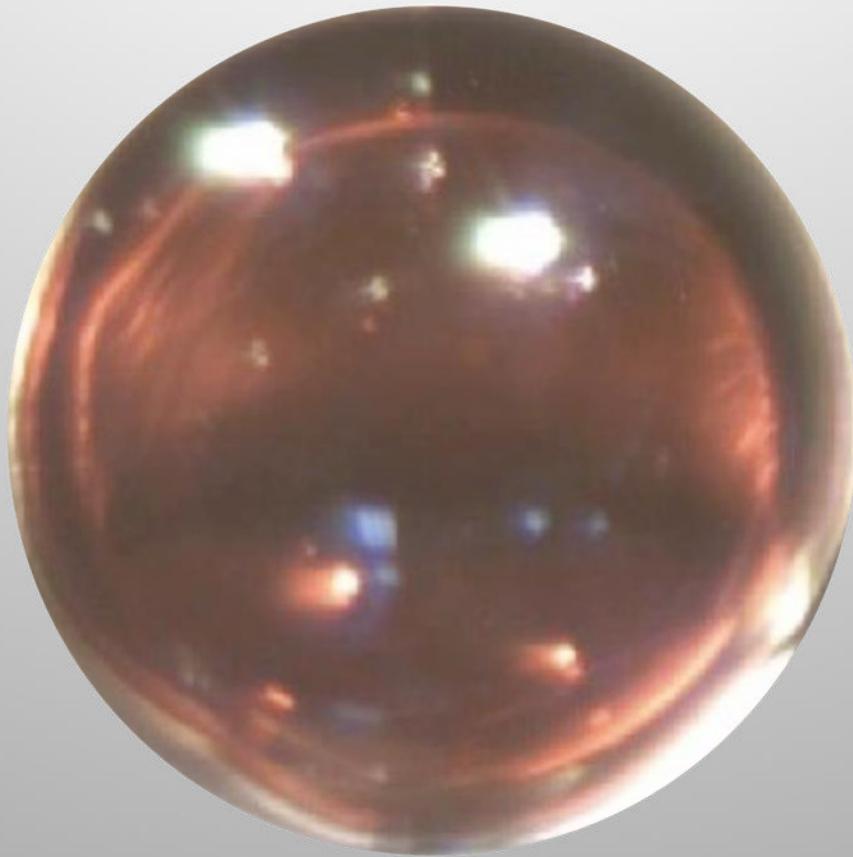


- Backscatter losses $\sim 15\% \text{ (~} 200\text{kJ)}$
- Capsule drive is over-predicted $\sim 200\text{kJ} \rightarrow$ drive degradation required for 2D HYDRA simulations to match experiment
- Suprathermal electron generation (0.5 - 2 kJ)
- Poor late-time inner beam propagation requires high inner beam power to achieve implosion symmetry
- Require cross-beam energy transfer (CBET) to control implosion symmetry \rightarrow leads to time-dependent asymmetries

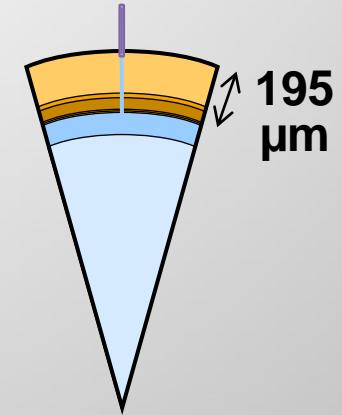
Cryogenic Ignition target



Plastic Ignition Capsule

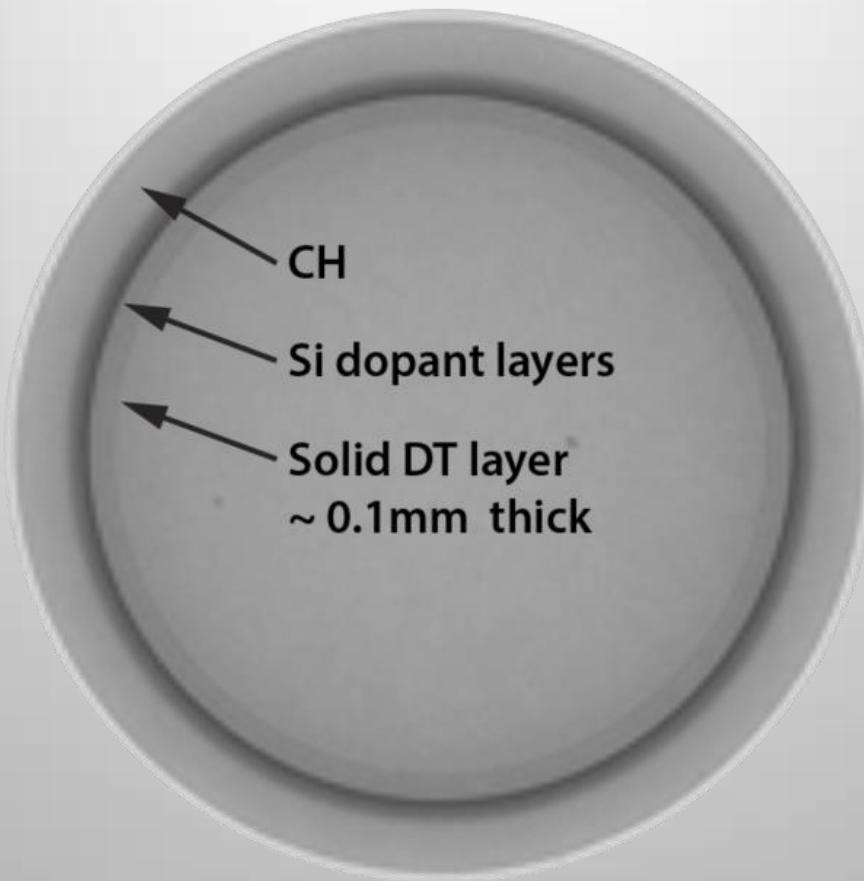


~2 mm diameter



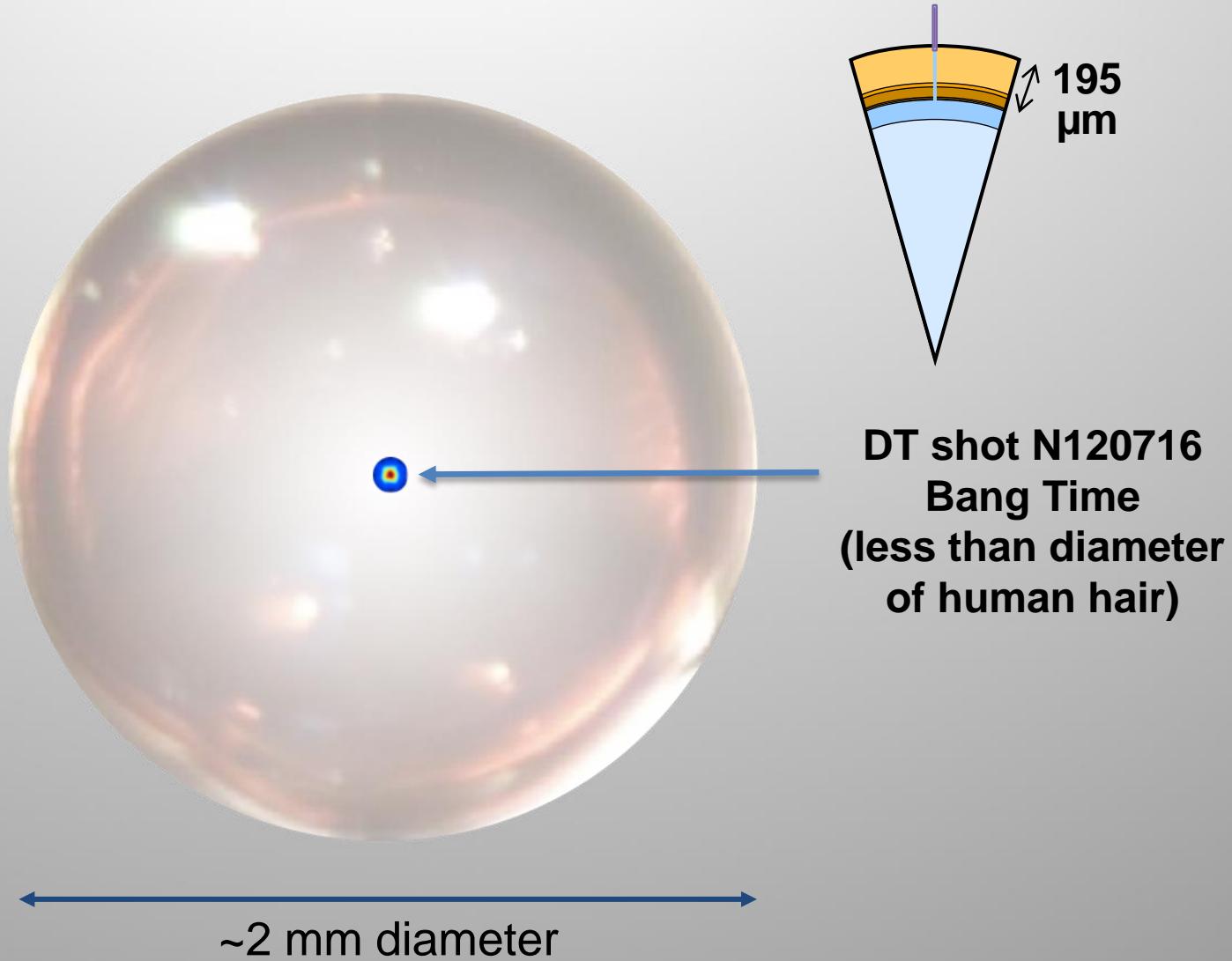
X-ray picture of capsule taken down axis of the hohlraum just before a shot

2mm diameter capsule

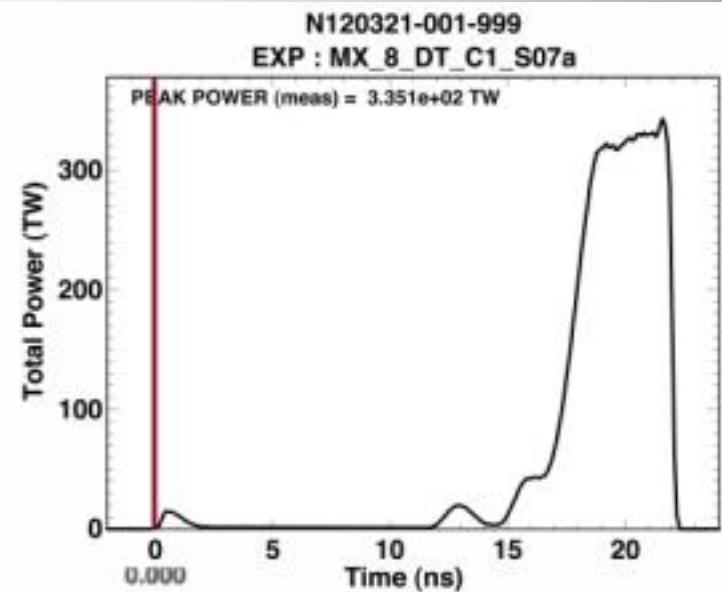
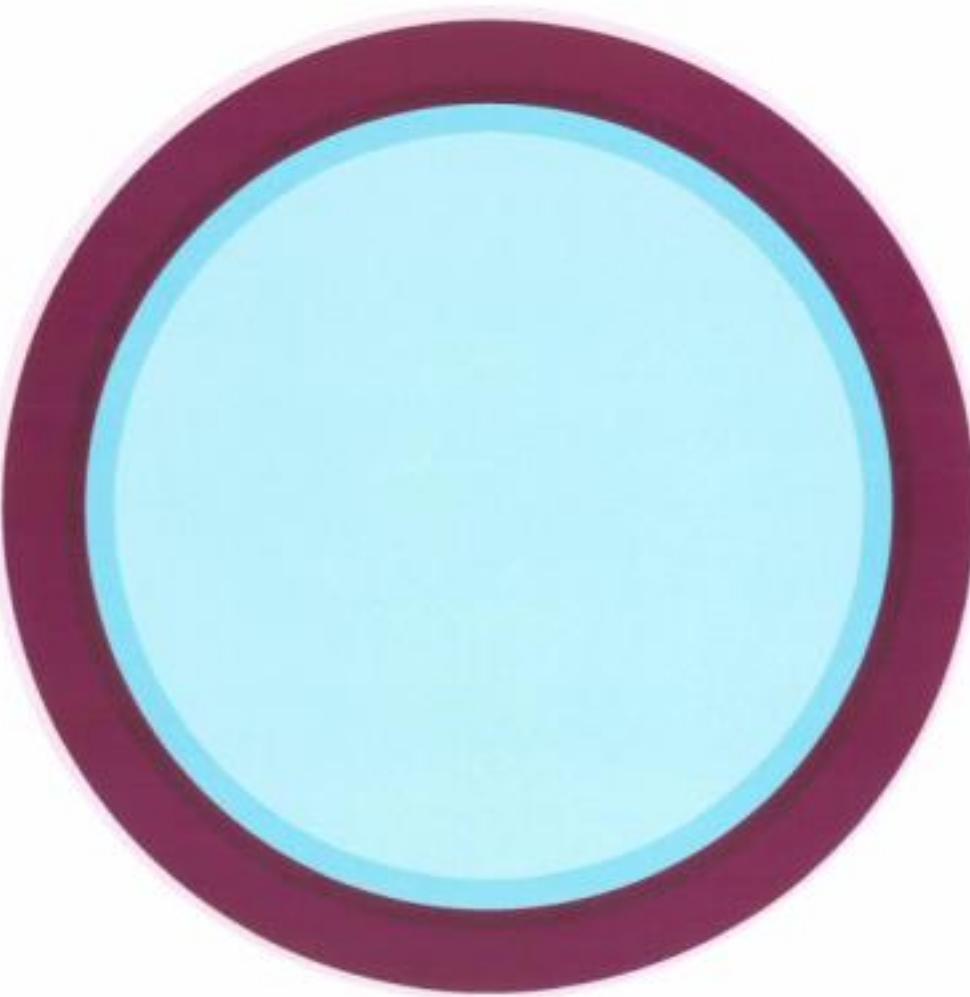


The challenge

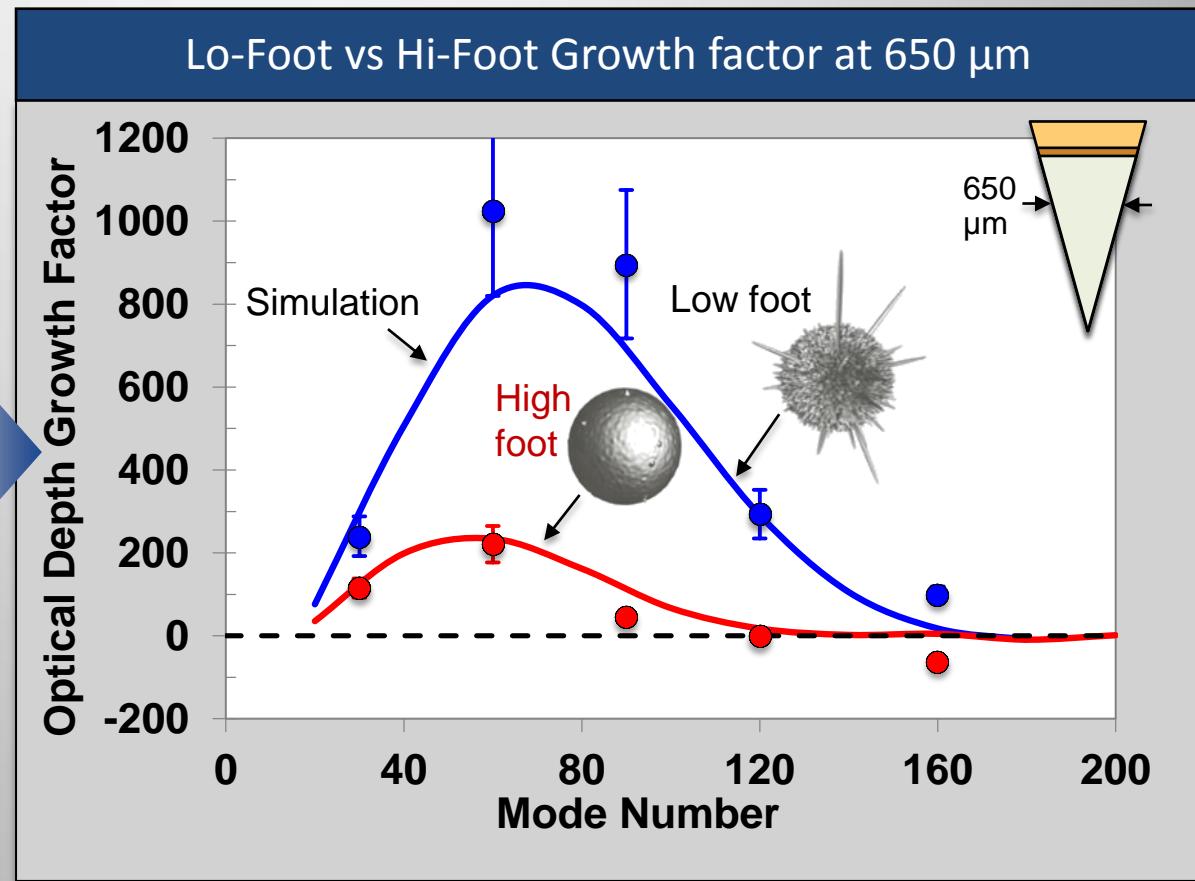
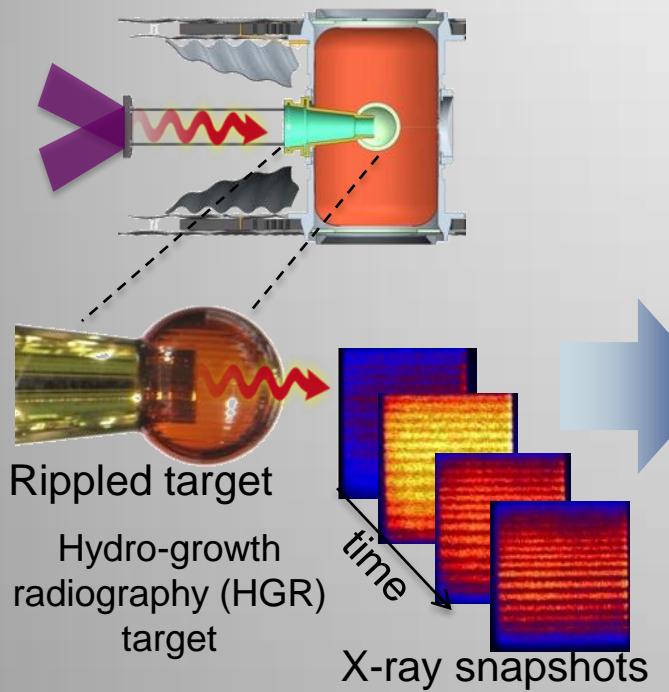
— near spherical implosion by ~35X



The capsule must be designed to withstand hydrodynamic instabilities



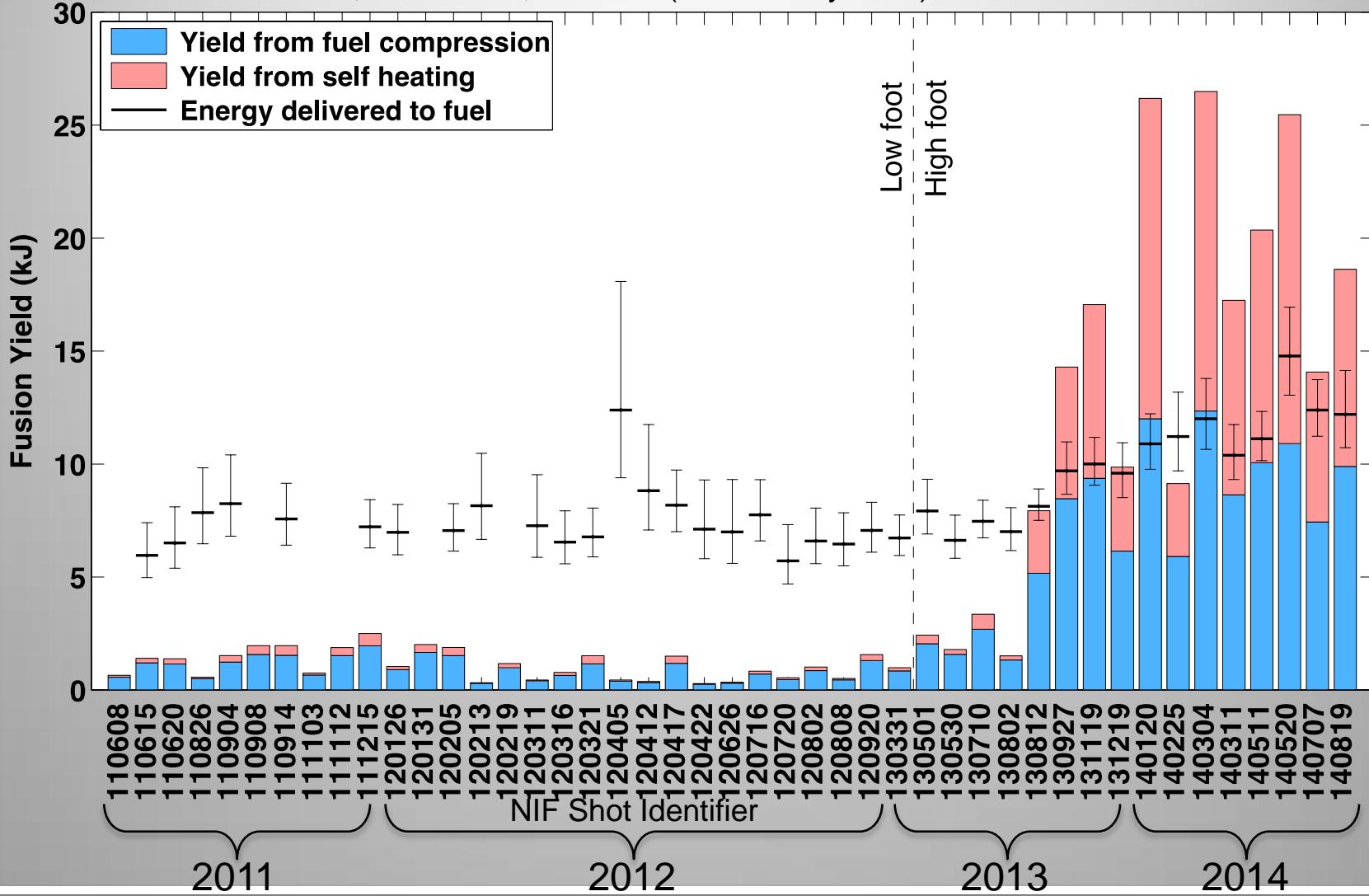
High Foot Campaign increased the power in the start of the laser drive to reduce hydrodynamic instabilities → experimentally confirmed



Raman, Peterson, Smalyuk, Robey

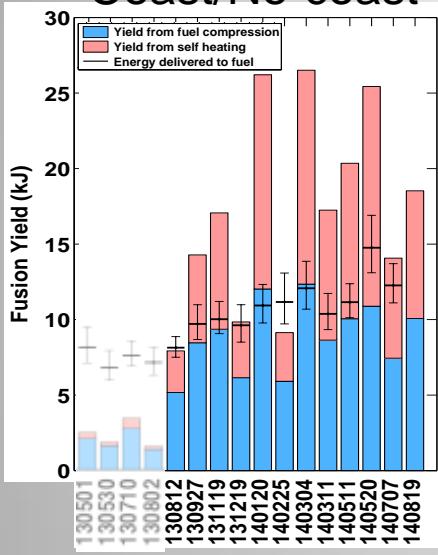
High Foot¹ experiments represent a seed change in performance – exhibiting significant alpha heating

¹ O. Hurricane et al, Nature 506, 343–348 (20 February 2014)

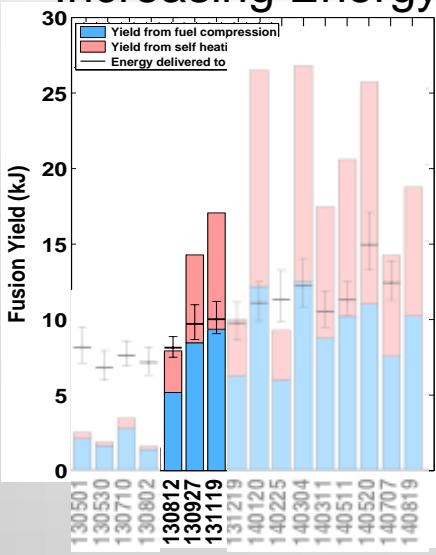


Controlling instability with High Foot pulses lets us probe other parameters and obtain a 'derivative' in a complex parameter space

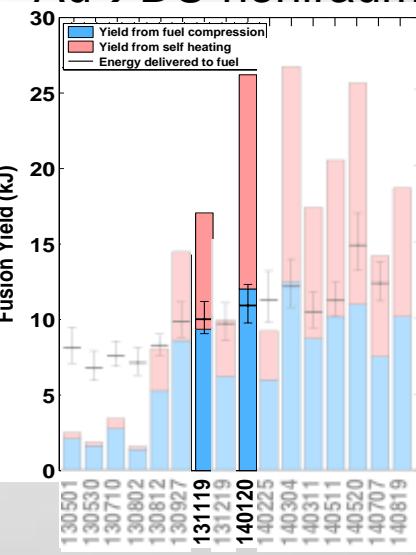
Coast/No-coast



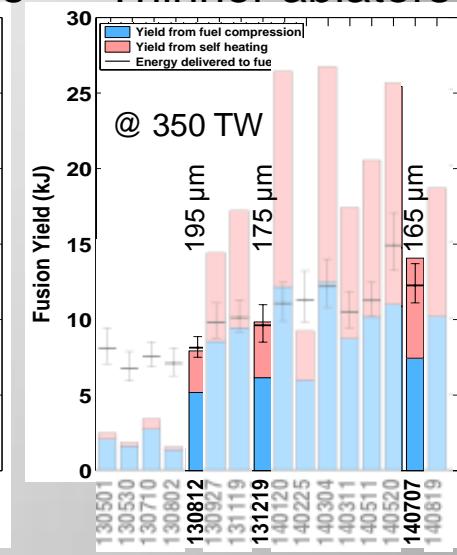
Increasing Energy



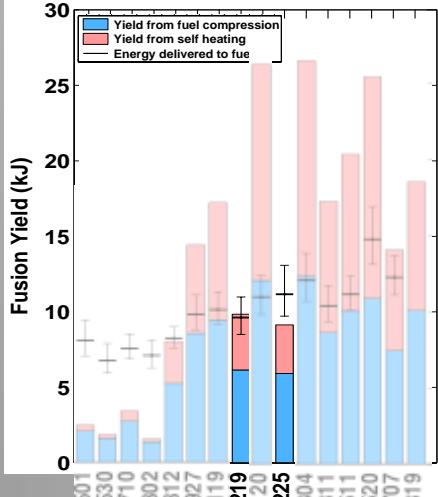
Au \rightarrow DU hohlraums



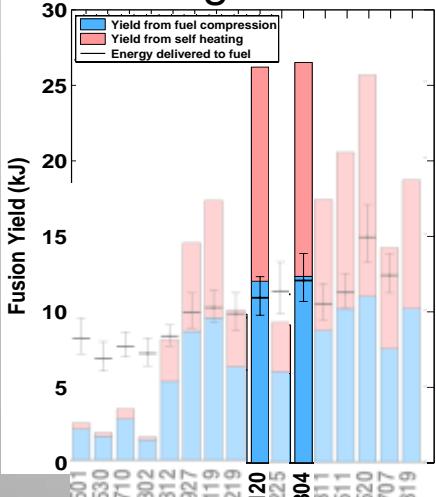
Thinner ablators



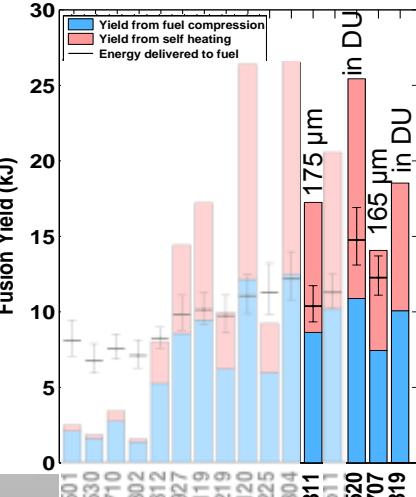
Repeat?



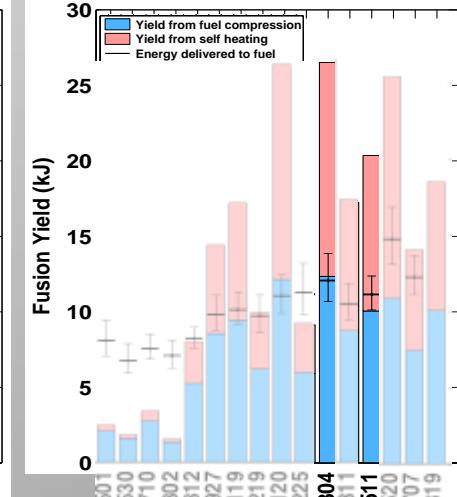
DU higher drive



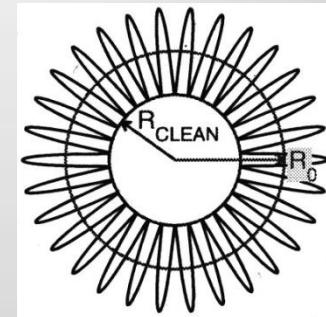
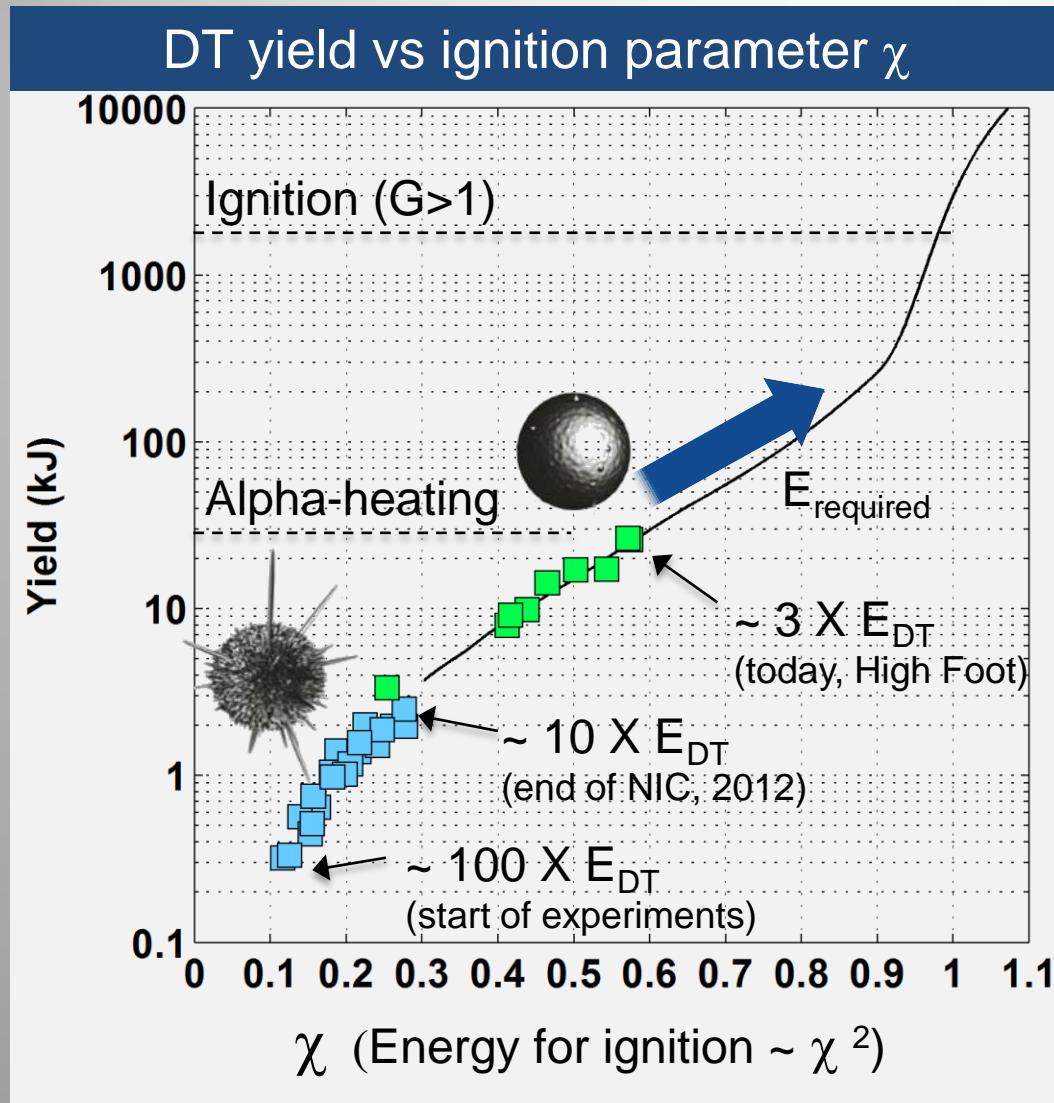
Thinner Au \rightarrow DU



Full Quench



Clear progress on the road to ignition → challenges still remain

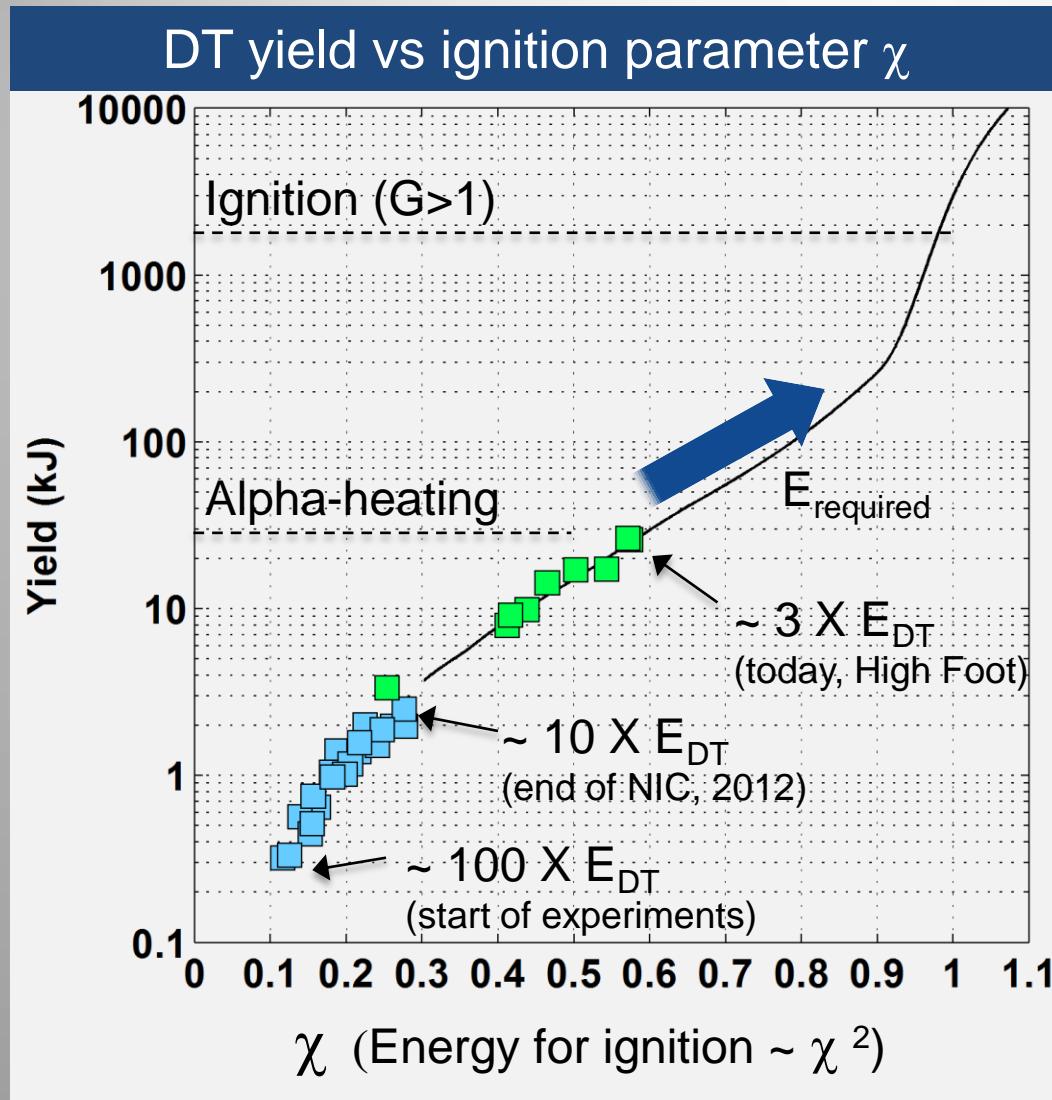


High Foot has demonstrated improved control over high-mode instabilities

Ignition requires:

- Improved implosion symmetry
- Increased implosion velocity
- Increased hot spot compression

Clear progress on the road to ignition → challenges still remain



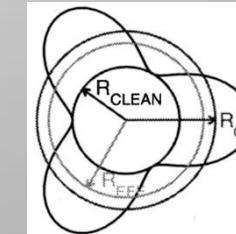
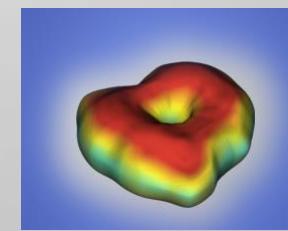
$$P_{\text{stag}} \sim p_{\text{abl}}^{2/5} \frac{v_{\text{imp}}^3}{\alpha^{9/10}} \mathcal{E}$$

Ignition requires:

Improved implosion symmetry

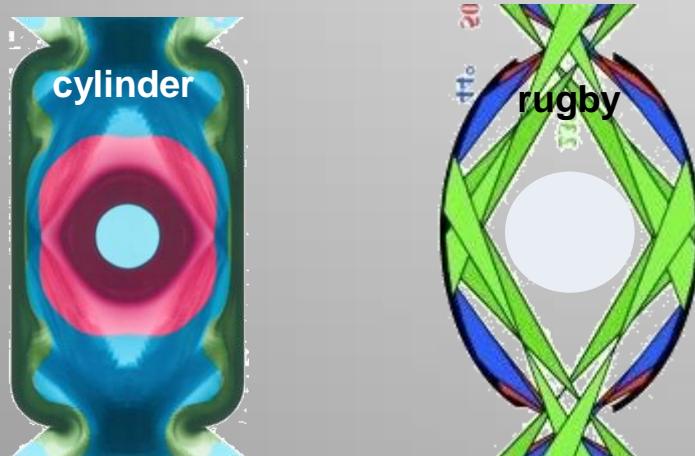
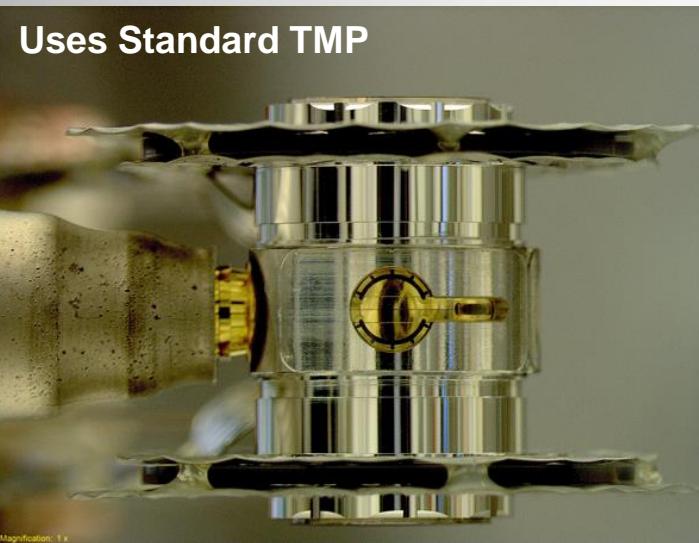
Increased implosion velocity

Increased hot spot compression

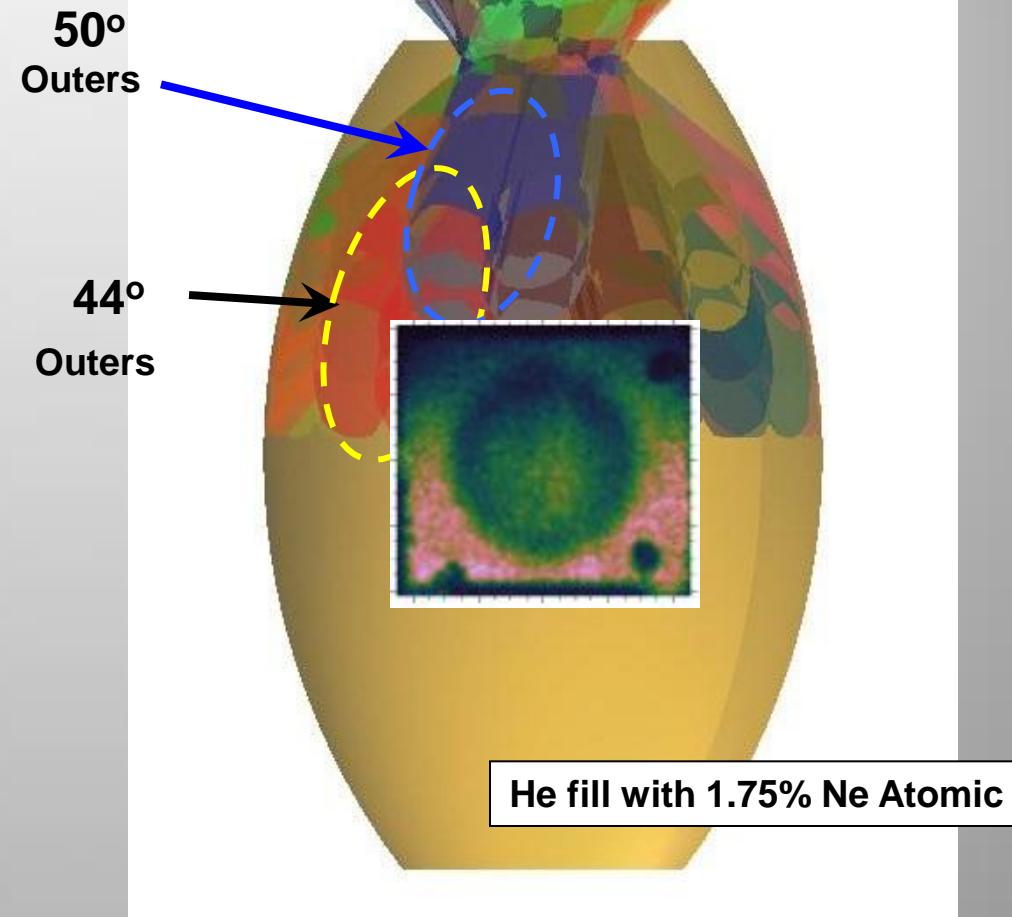


Low mode asymmetry control
still needs to be improved

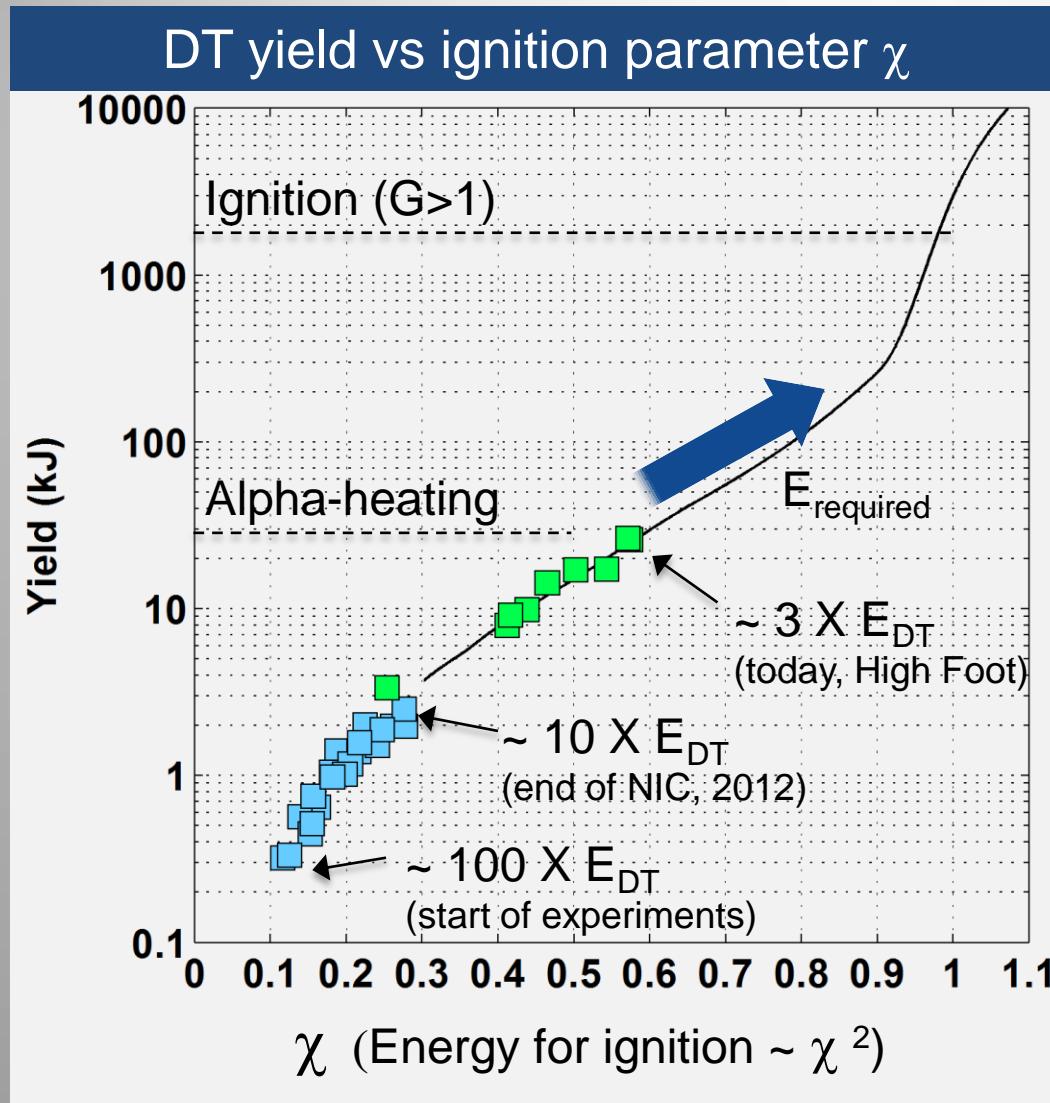
Rugby hohlraums are currently under investigation to address implosion symmetry challenges



Smooth beam coverage along hohlraum wall



Clear progress on the road to ignition → challenges still remain



Ignition requires:

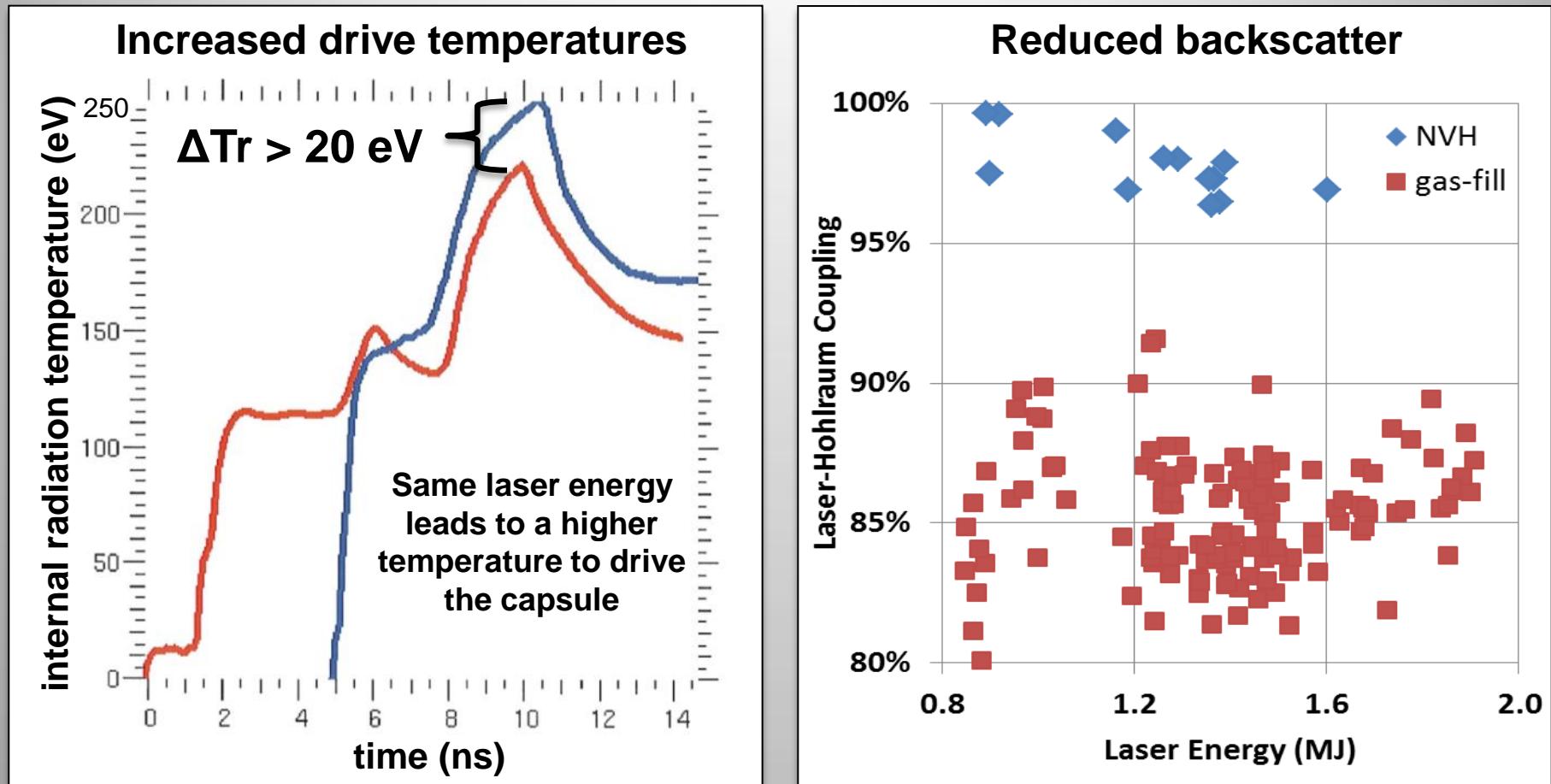
Improved implosion symmetry

Increased implosion velocity

Increased hot spot compression

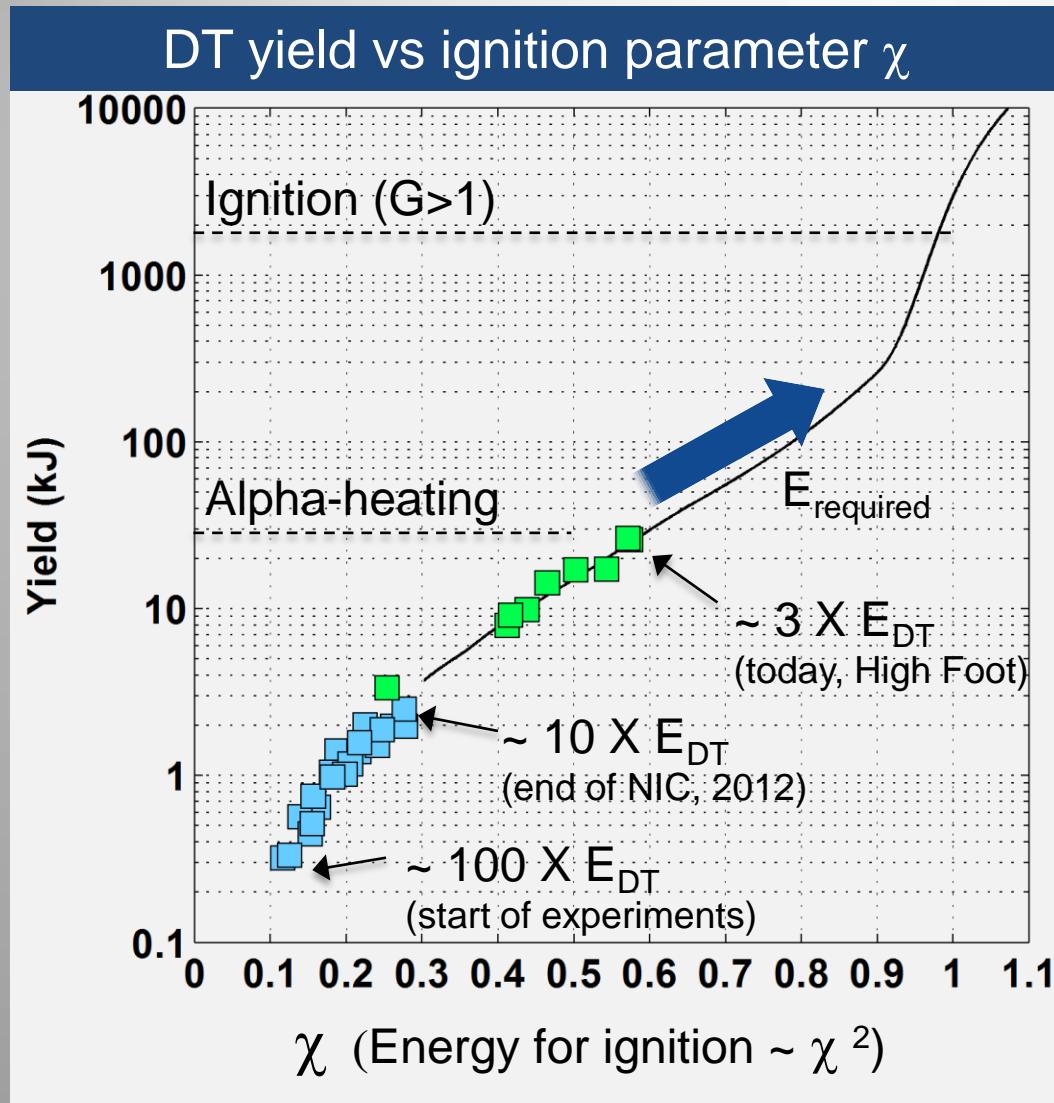
$$P_{stag} \sim p_{abl}^{2/5} \frac{v_{imp}^3}{\alpha^{9/10}} \epsilon$$

Near-vacuum (low He gas-fill) hohlraums have reduced laser-plasma interactions and improved hohlraum efficiency



Near-vacuum hohlraums have also measured a 100x reduction in suprathermal electron generation

Clear progress on the road to ignition → challenges still remain



Ignition requires:

Improved implosion symmetry

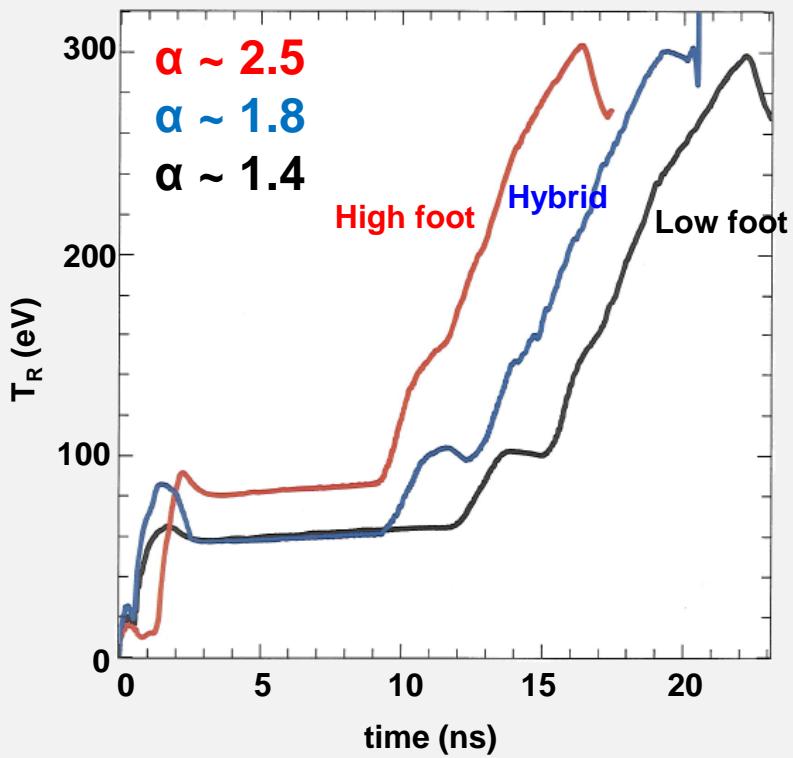
Increased implosion velocity

**Increased hot spot compression
(reduced entropy/adiabat)**

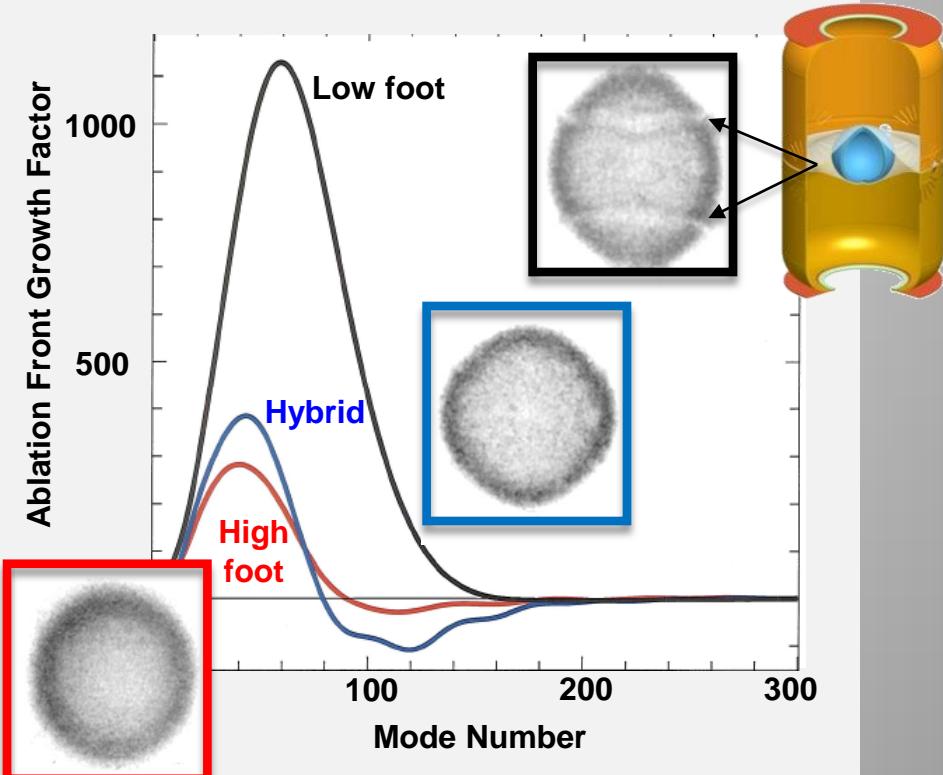
$$P_{\text{stag}} \sim P_{\text{abl}}^{2/5} \frac{v_{\text{imp}}^3}{\alpha^{9/10}} \epsilon$$

Directed pulse shaping (“adiabat shaping”) is predicted to decrease adiabat (increase compression, ρR) while preserving favorable stability

Hohlraum internal temperature



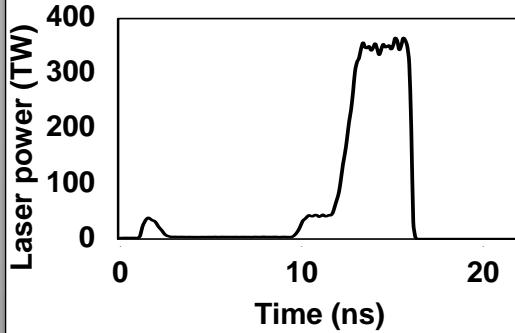
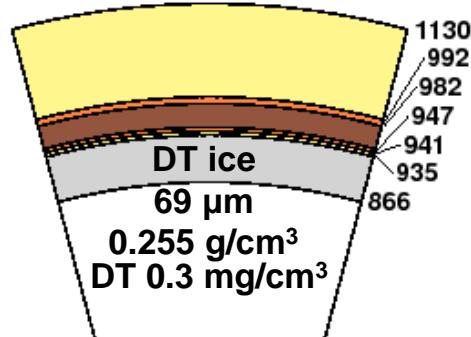
Predicted ablation front growth factors



We have begun exploring this concept through a series of focused experiments and recently, integrated DT layered implosions tests

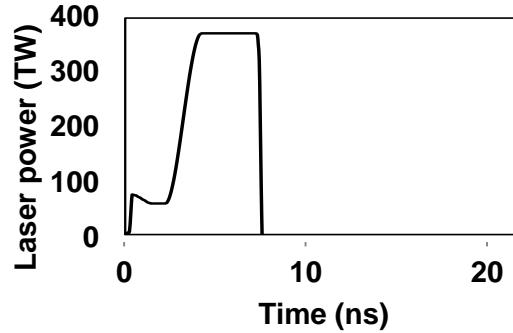
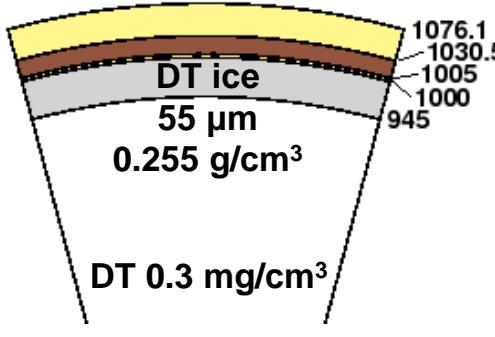
We are also exploring alternate ablator materials – Different benefits and different challenges

Si-doped CH
(1.1 g/cc)



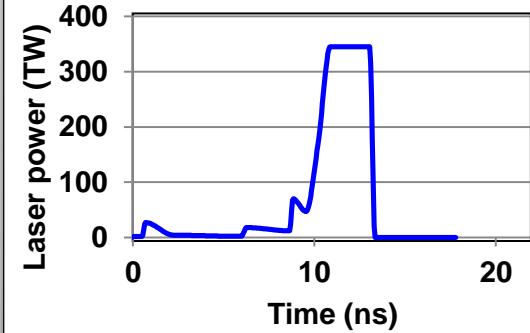
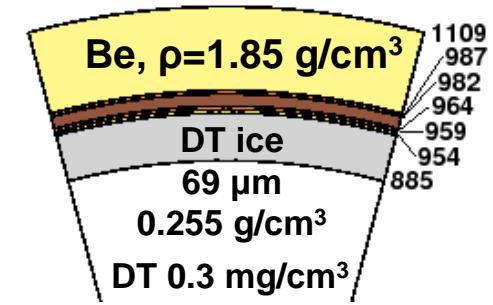
- Long pulse
- Low ρ , lower absorbed E
- Easily doped, fab'd

W-doped HDC
(3.5 g/cc)



- Short pulse
- Ablator EOS?
- Obtaining dopant level?

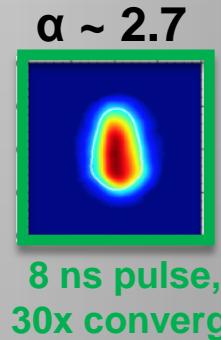
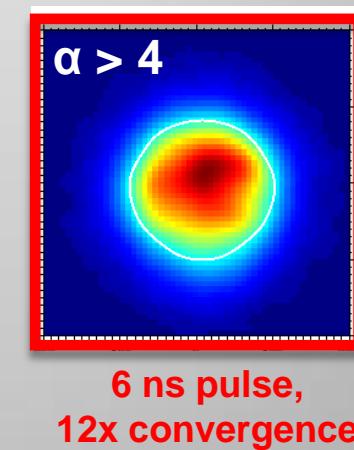
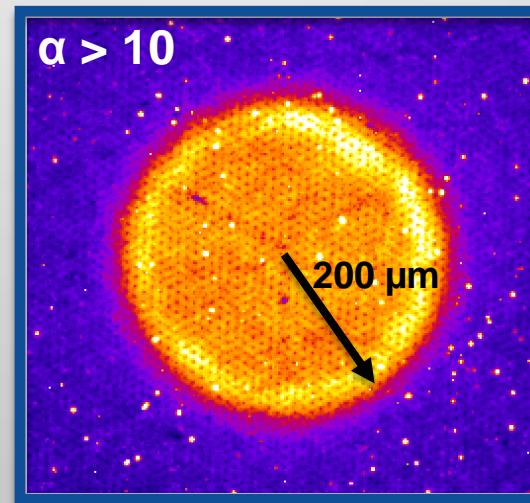
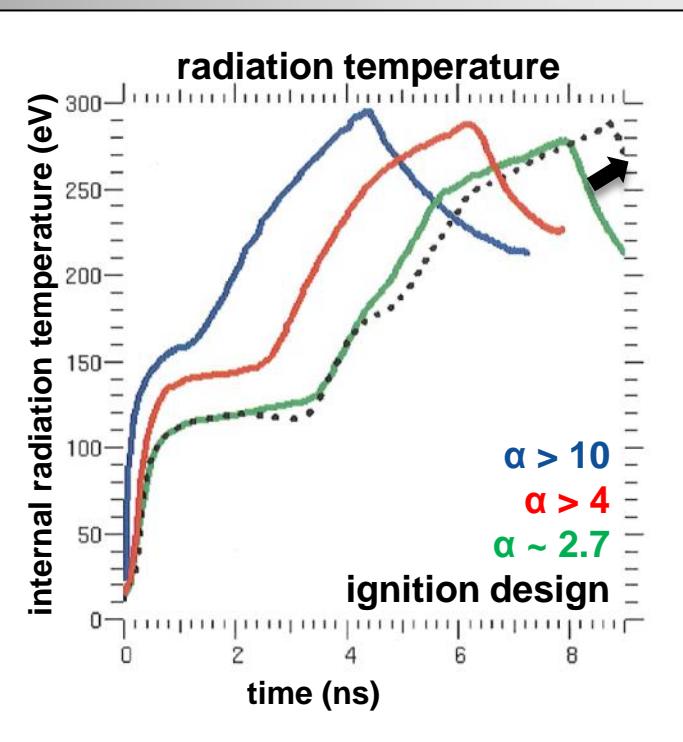
Cu-doped Be
(1.85 g/cc)



- Intermediate pulse
- Ablator microstructure?
- X-ray preheat?

The high density of diamond (HDC) ablators may enable using near-vacuum hohlraums to reach significant alpha heating

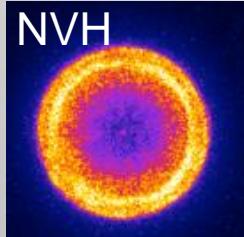
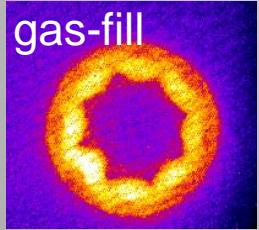
Implosions in near-vacuum hohlraums have been extended from short pulse, low convergence → ignition-relevant, high convergence



Symmetry control is an ongoing challenge

Exciting progress on hohlraum and capsule performance depends on NIF's unique and expanding suite of diagnostics

Viewfactors (2/3 hohlraum)



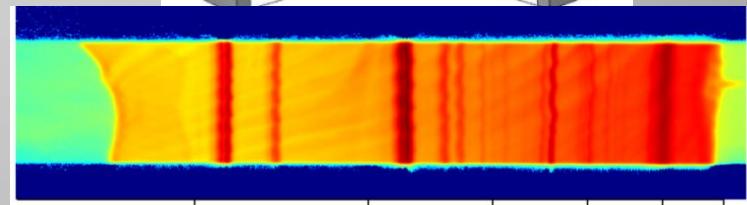
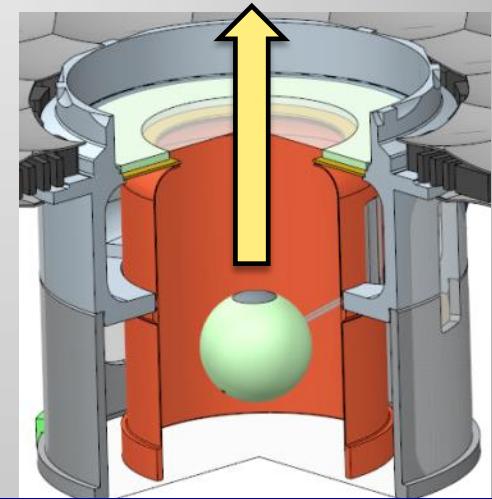
Diagnose wall motion and drive spectrum



Hohlraum plasma conditions

Dot Spectroscopy

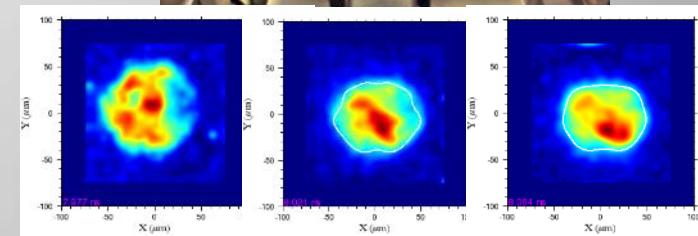
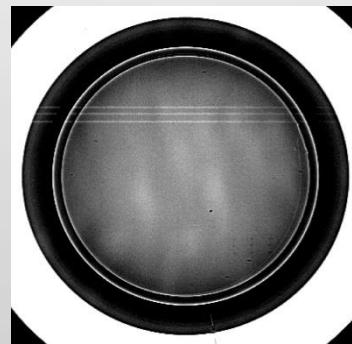
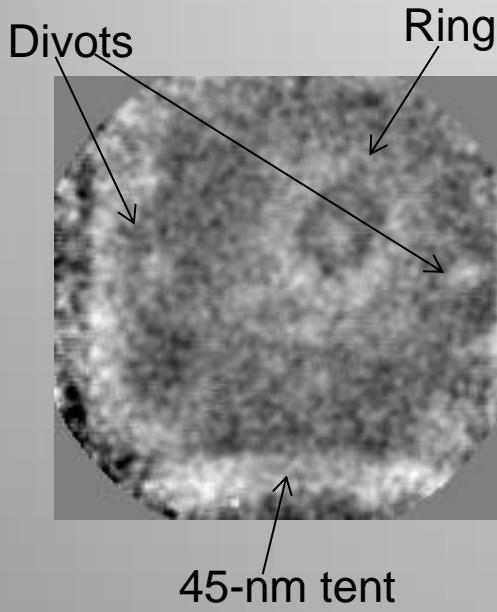
Time resolved spectrometer (NXS)



Measure internal plasma temperature

Exciting progress on hohlraum and capsule performance depends on NIF's unique and expanding suite of diagnostics

Native surface roughness (“Ultimate” HGR) hydro instability measurements



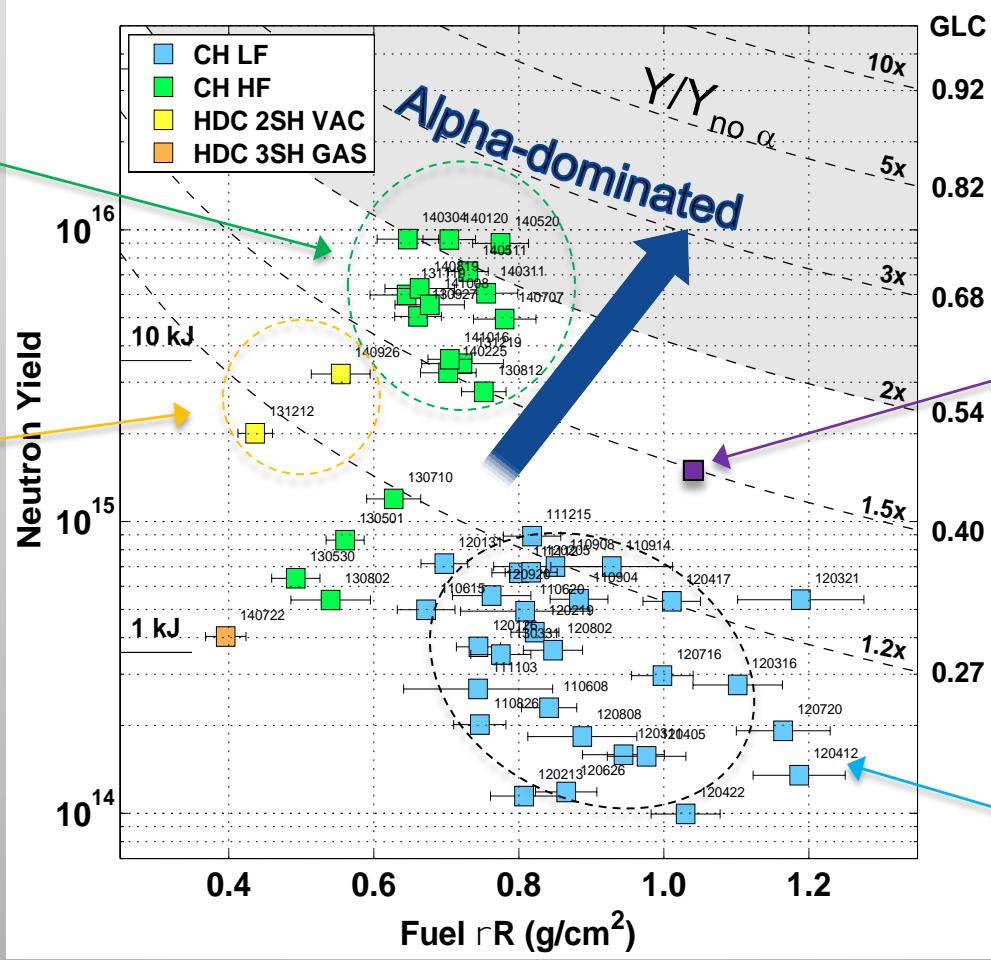
DIXI (Dilation X-ray Imager) fast resolution (~10 ps) of burning core

Capsule implosion

We are developing a promising path forward with low mix, high velocity implosions and improving symmetry control to reach toward higher yields

High foot

HDC NVH





**Lawrence Livermore
National Laboratory**